

The Square Kilometre Array

Joseph Lazio

SKA Project Scientist

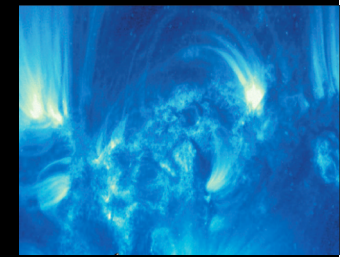
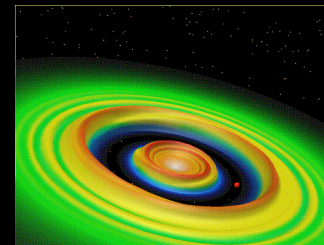
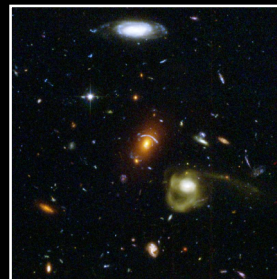
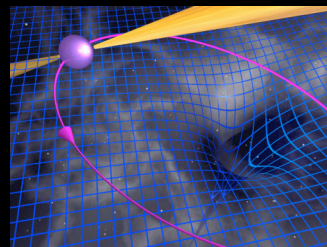
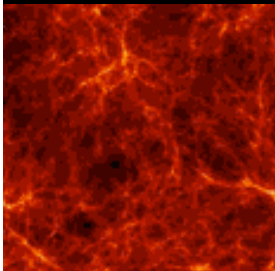
Naval Research Laboratory

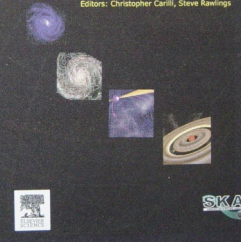
<http://www.skatelescope.org/>

Square Kilometre Array

The Global Radio Wavelength Observatory

- Originally: “Hydrogen telescope”
 - Detect H I 21-cm emission from Milky Way-like galaxy at $z \sim 1$
- SKA science much broader
 - ⇒ Multi-wavelength, multi-messenger
- On-going technical development
- International involvement





21st Century Astrophysics



20th Century: We discovered our place in the Universe

21st Century: We understand the Universe we inhabit

Do We Understand the Extremes of the Universe?

- Gravity
 - Can we observe strong gravity in action? (radio pulsar tests of GR)
 - What is dark matter and dark energy? (dark energy and BAOs with H I galaxies)
- Magnetism
- Strong force
 - Nuclear equation of state

How do Galaxies Form and Evolve? What is the Origin and Evolution of Stars and Planets?

- Galaxies and the Universe
 - How did the Universe emerge from its Dark Ages?
 - How did the structure of the cosmic web evolve?
 - Where are most of the metals throughout cosmic time?
 - How were galaxies assembled?
- Stars, Planets, and Life
 - How do planetary systems form and evolve?
 - What is the life-cycle of the interstellar medium and stars? (biomolecules)
 - Is there evidence for life on exoplanets? (SETI)

Origins

First Light

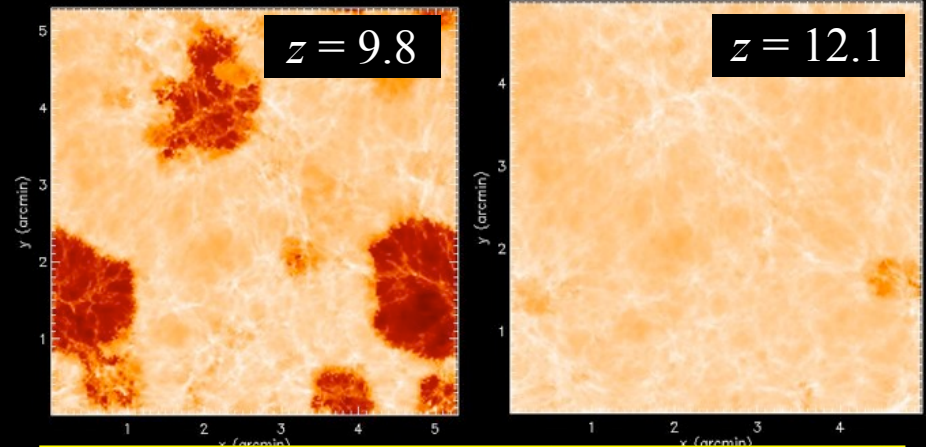
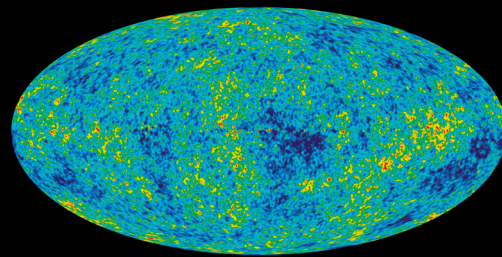
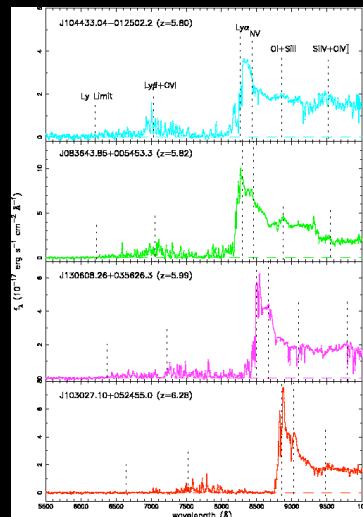
Galaxy Evolution

Astrobiology

Epoch of Reionization

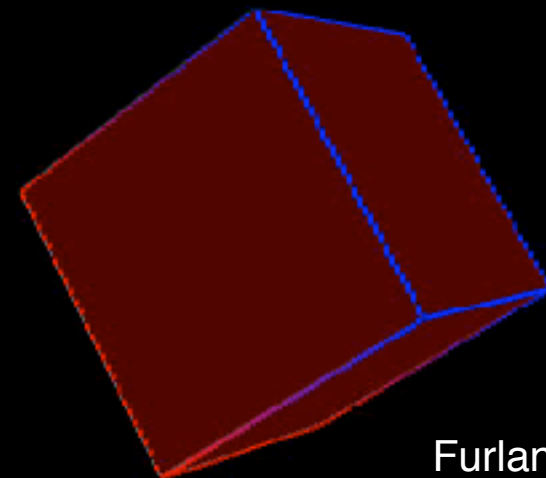


- Most baryons in form of H I (neutral hydrogen)
- Universe made rapid transition from largely neutral to largely ionized ($z_{\text{ion}} \sim 6-11$)



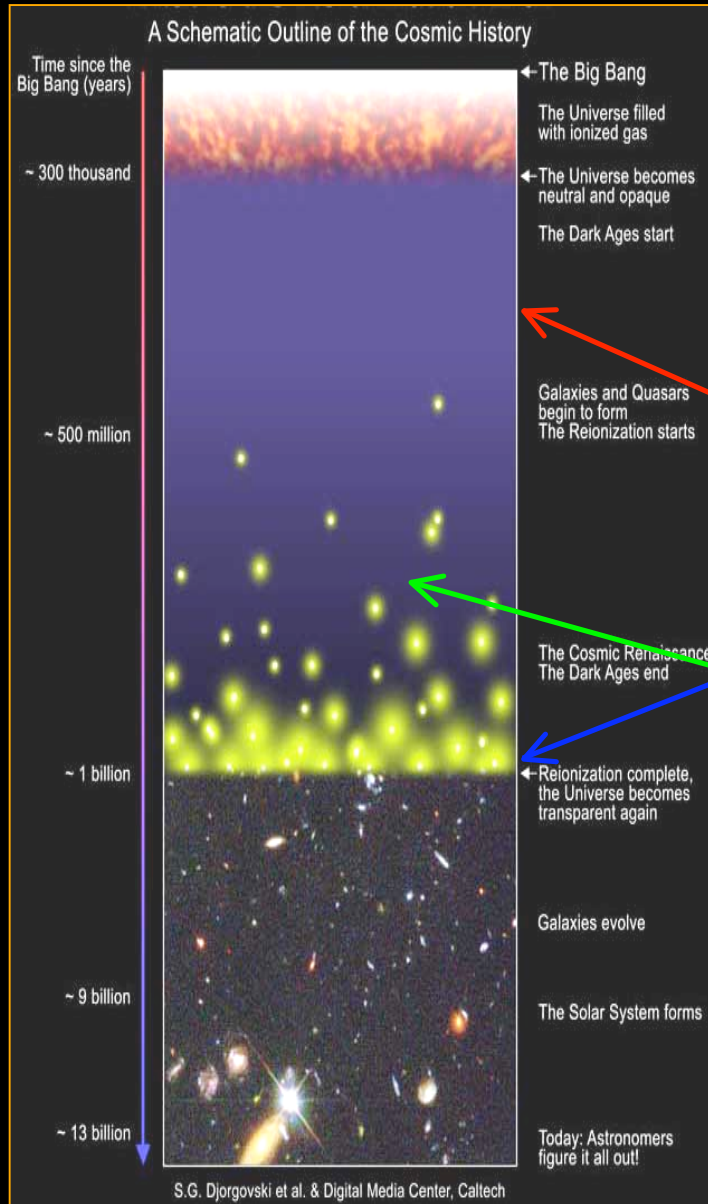
SKA objective: Image the IGM transition in the H I (21-cm) line

- Gunn-Peterson trough in high-z quasars
- Electron scattering opacity in CMB analysis

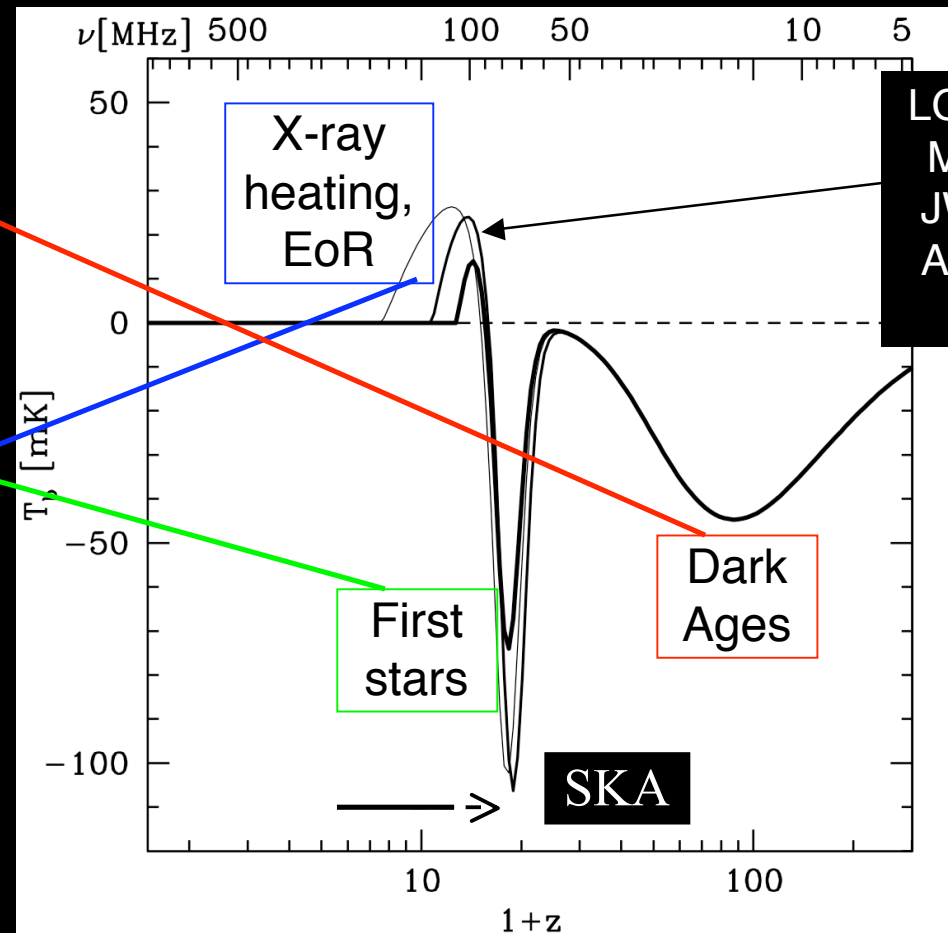


Furlanetto et al.; Gnedin

Evolution of the Universe



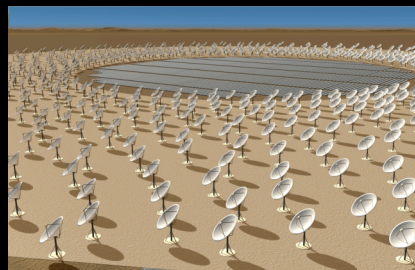
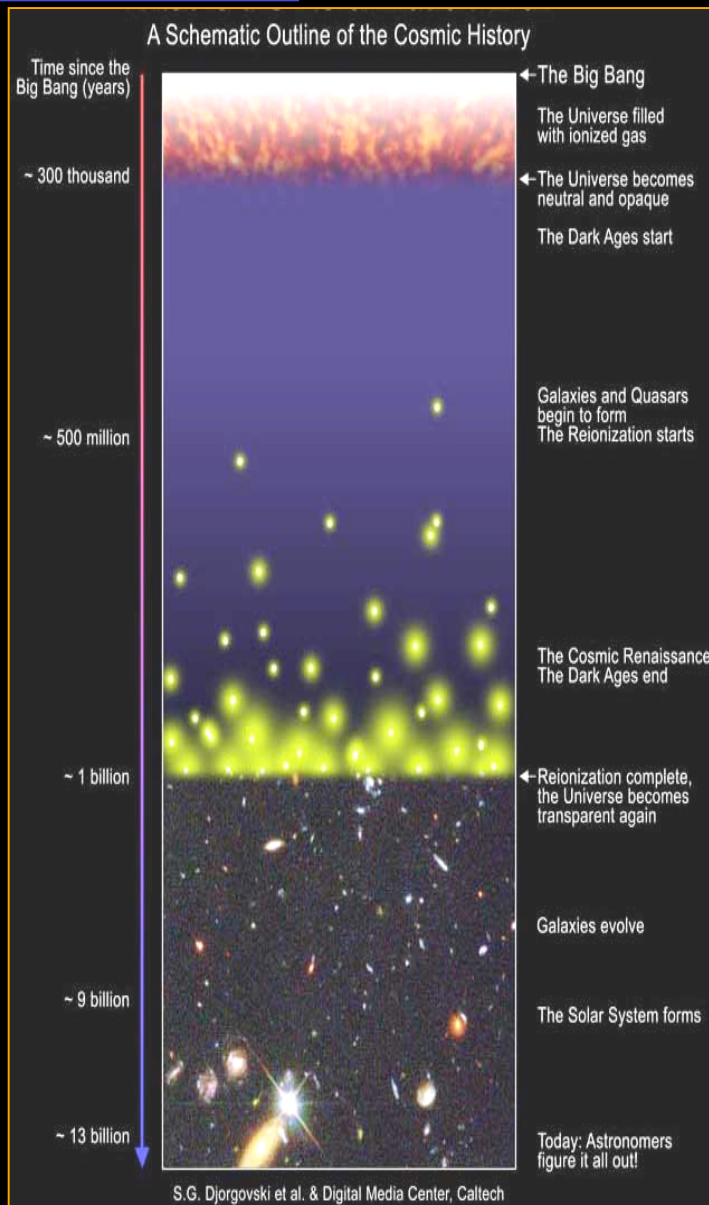
H I brightness temperature signal (w.r.t. CMB)



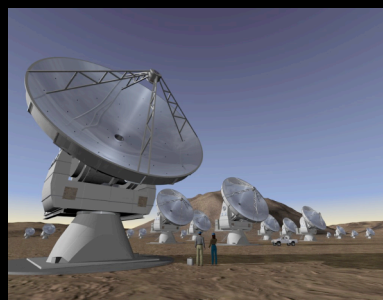
LOFAR,
 MWA,
 JWST,
 ALMA,
 ...

(Pritchard & Loeb 2008)

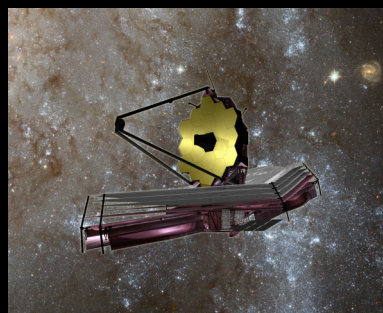
Epoch of Reionization



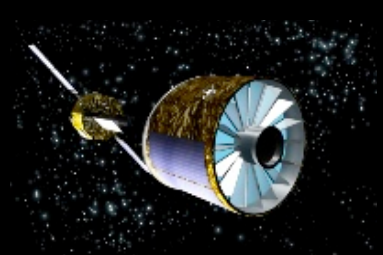
SKA: IGM and First Galaxies



ALMA: First Galaxies



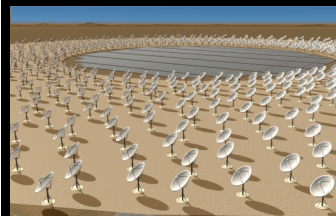
JWST: First Stars and Galaxies



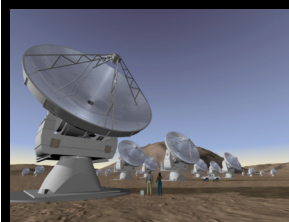
X-rays: First Black Holes

Origins
First Light
Galaxy Evolution
Astrobiology

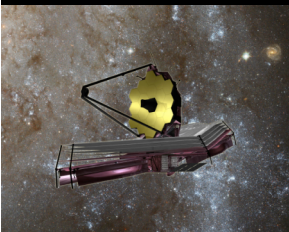
Galaxy Assembly & Evolution



SKA: atomic gas, star formation, feedback



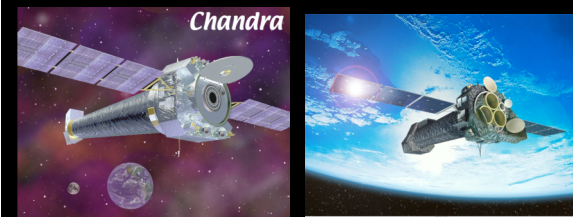
ALMA: molecular gas, star formation



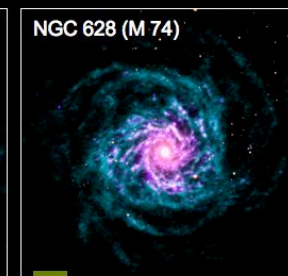
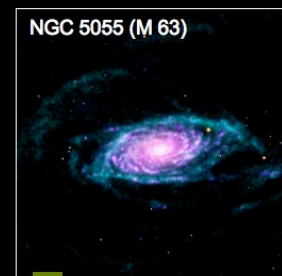
JWST: dust, star formation



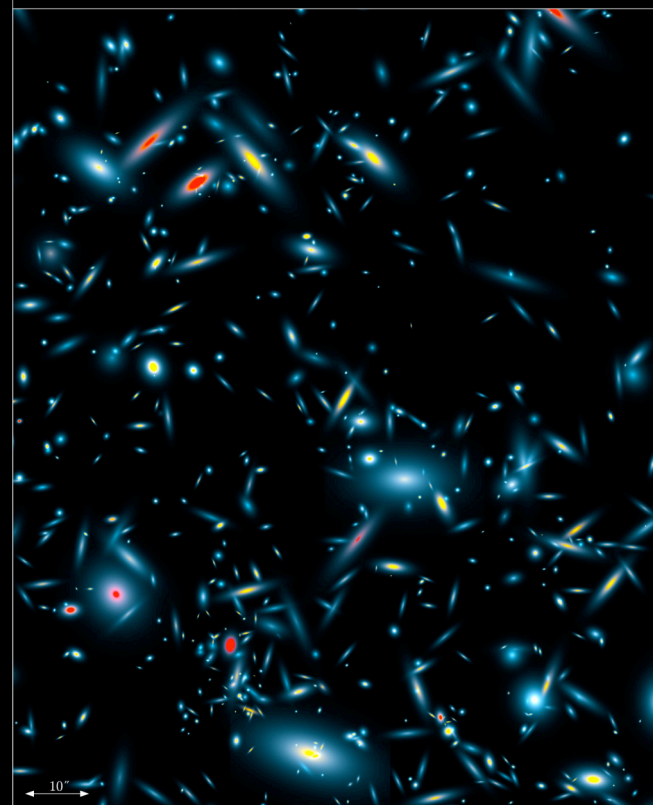
Optical/UV: stars, star formation



X- and γ -rays: feedback



SKA Design Studies – Hydrogen Simulation at $z=1$



■ Atomic Hydrogen (hyperfine emission-line at 1.4 GHz rest-frame)
■ Carbon Monoxide (1-0 emission-line at 115 GHz rest-frame)
■ Carbon Monoxide (6-5 emission-line at 692 GHz rest-frame)

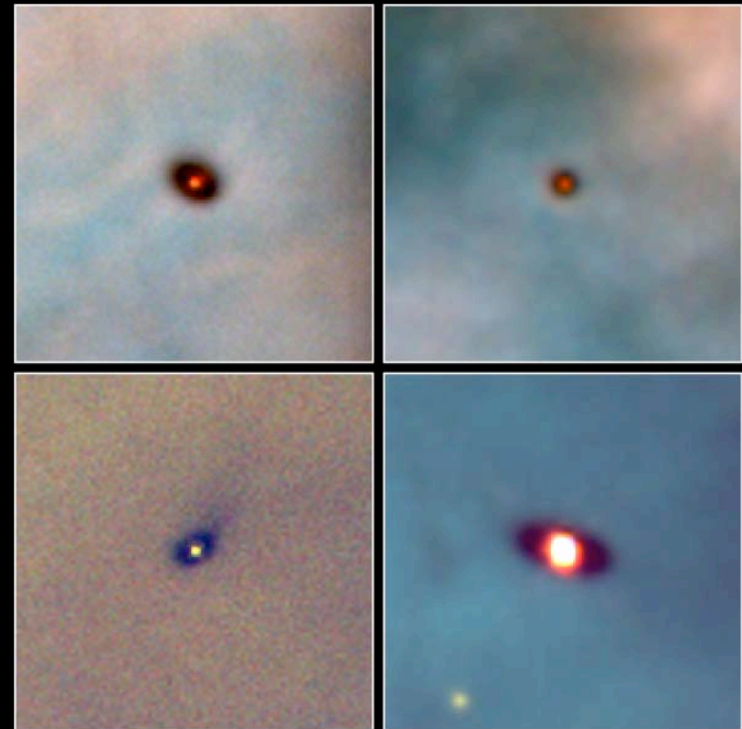
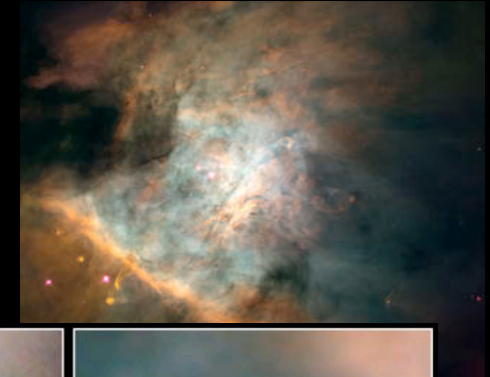
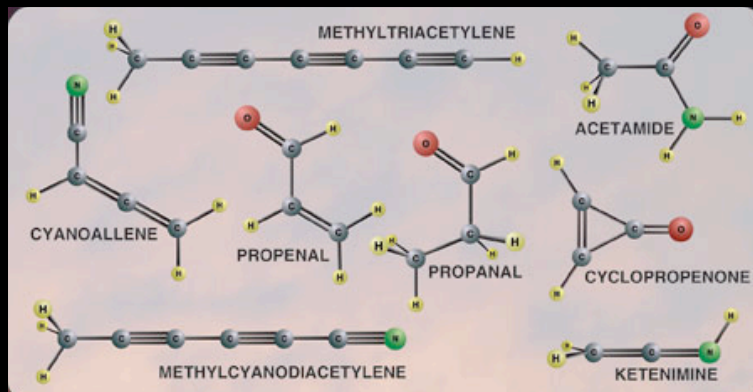
University of Oxford
April 2009
D. Obreschkow

Astrobiology at Long Wavelengths



$\lambda > 1 \text{ cm}$

- Not affected by dust
- Complex molecules have transitions at longer wavelengths
- “Waterhole” (1.4–1.7 GHz)
- Magnetically-generated emissions from extrasolar planets



Protoplanetary Disks
Orion Nebula

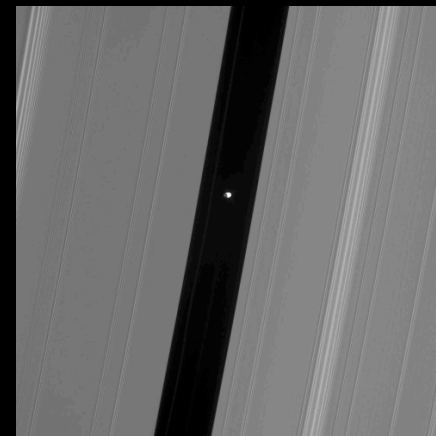
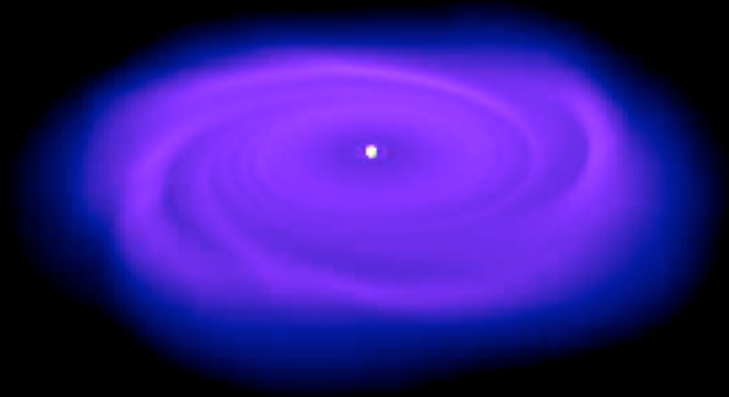
HST · WFPC2

PRC95-45b · ST ScI OPO · November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA

Protoplanetary Disks



- 1 cm wavelength probes thermal radiation from “pebbles”
- Disks optically thin
- Image nearby protoplanetary disks
 - Cf. ALMA, $< 700 \mu\text{m}$
 - mas resolution @ 1 cm is routine, all that’s lacking is *sensitivity*
- Orbital period @ 1 AU ~ 1 yr
 - movies

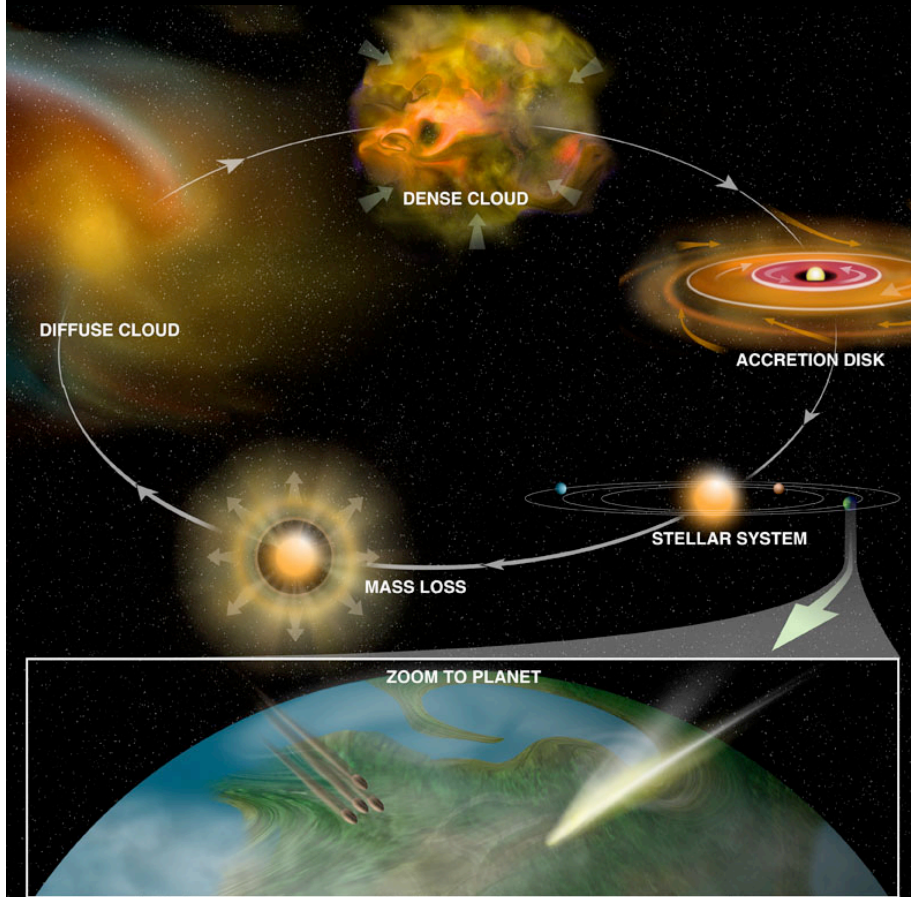


Mayer

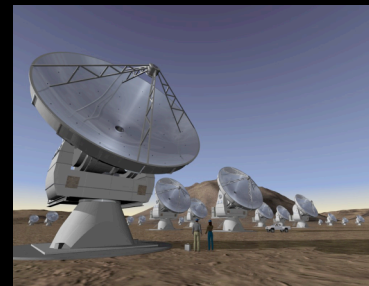
Origins
First Light
Galaxy Evolution
Astrobiology



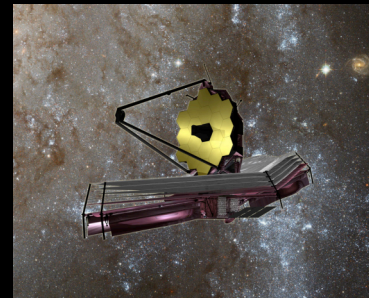
Astrobiology



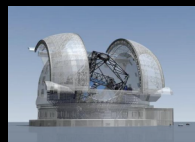
SKA:
protoplanetary
disks, molecules,
planets, SETI



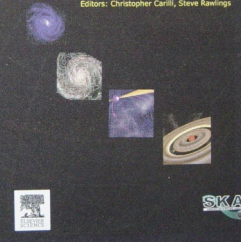
ALMA: protoplanetary
disks, molecules



JWST: protoplanetary
disks



Optical: protoplanetary
disks, planets



21st Century Astrophysics



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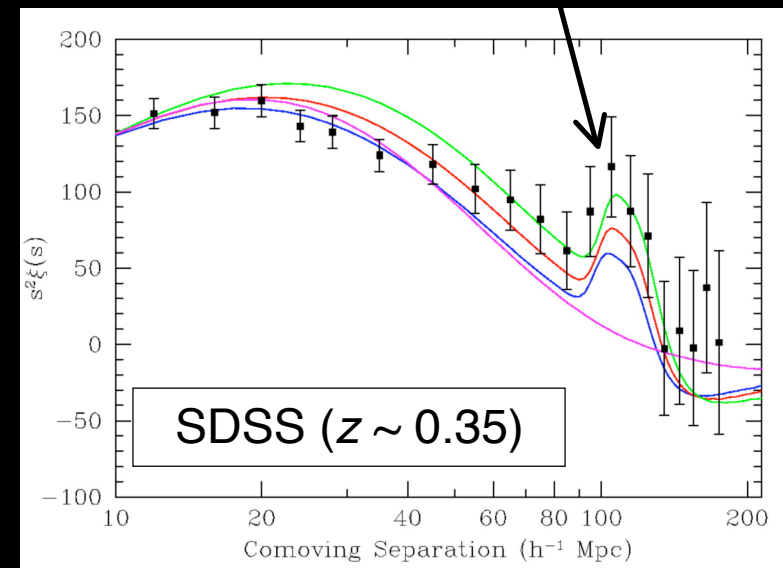
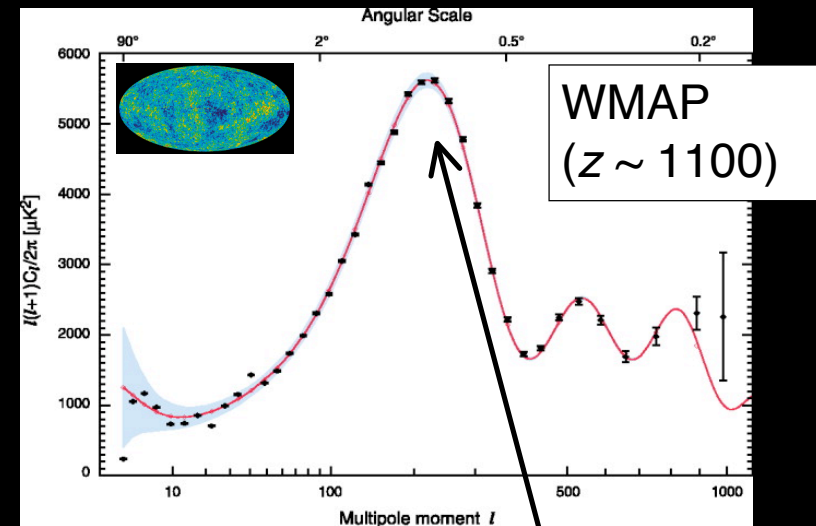
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Baryon Acoustic Oscillations

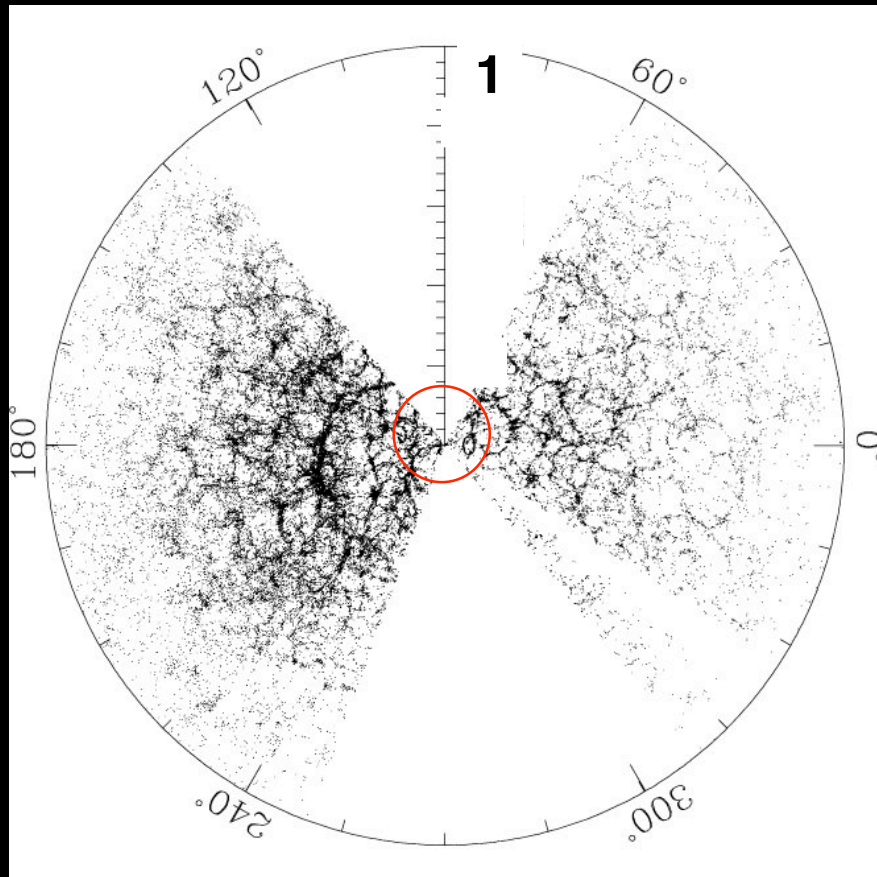


Remnant of plasma acoustic oscillations in early Universe

- $D_A(z)$ = angular size distance as a function of redshift
- $\sim 100 h^{-1}$ Mpc “standard ruler”
- Measures expansion rate of Universe



SKA: Stage IV BAOs



SDSS

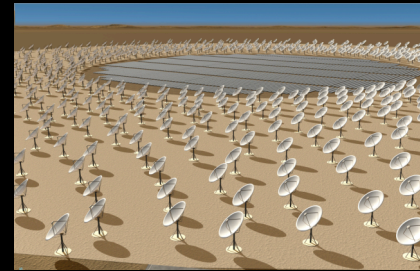
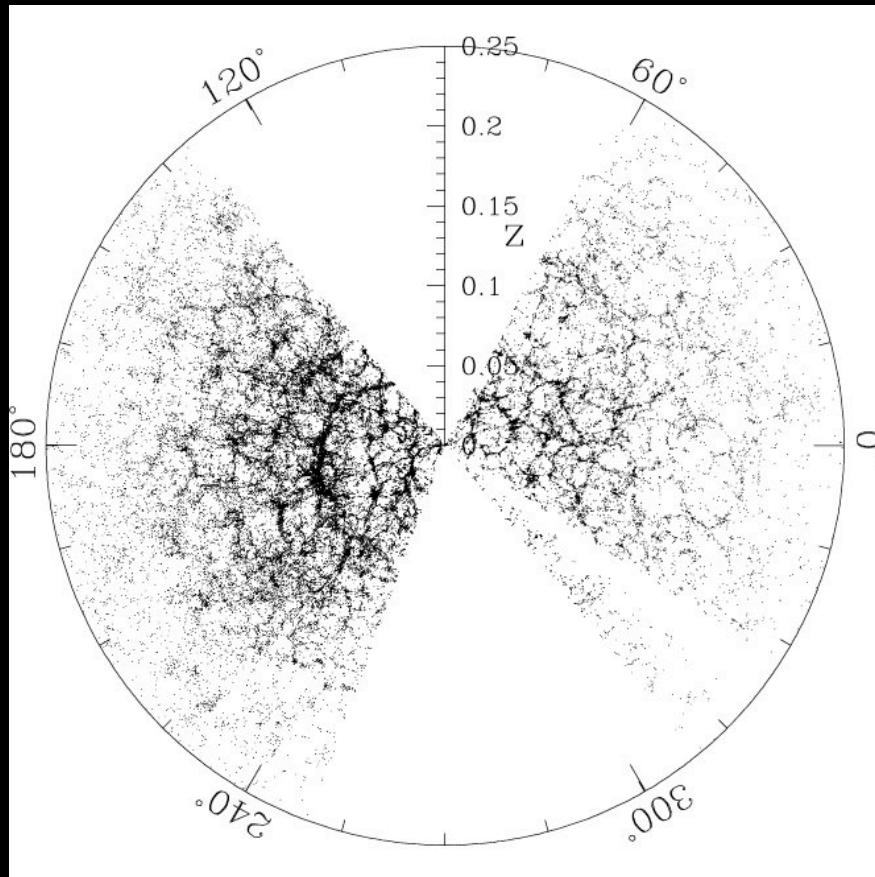
SKA

- Next-generation goal:
 - Survey large volume
 - Slice into redshift bins
 - Detect BAOs in each z bin
- SDSS surveyed $\sim 1 \text{ Gpc}^3$
 - One redshift bin ~ 0.35
- SKA targeting 100 Gpc^3 ($z > 1$)
- H I galaxies
 - Intrinsically spectroscopic survey
 - Different biases than LST, JDEM

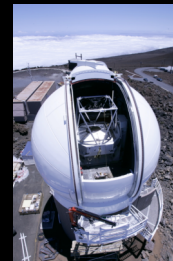
Fundamental
Physics

Dark Energy
GR & BHs
Strong Force

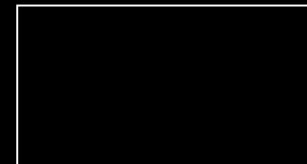
SKA: Stage IV BAOs



SKA: H I BAOs
("Billion-Galaxy
Survey")

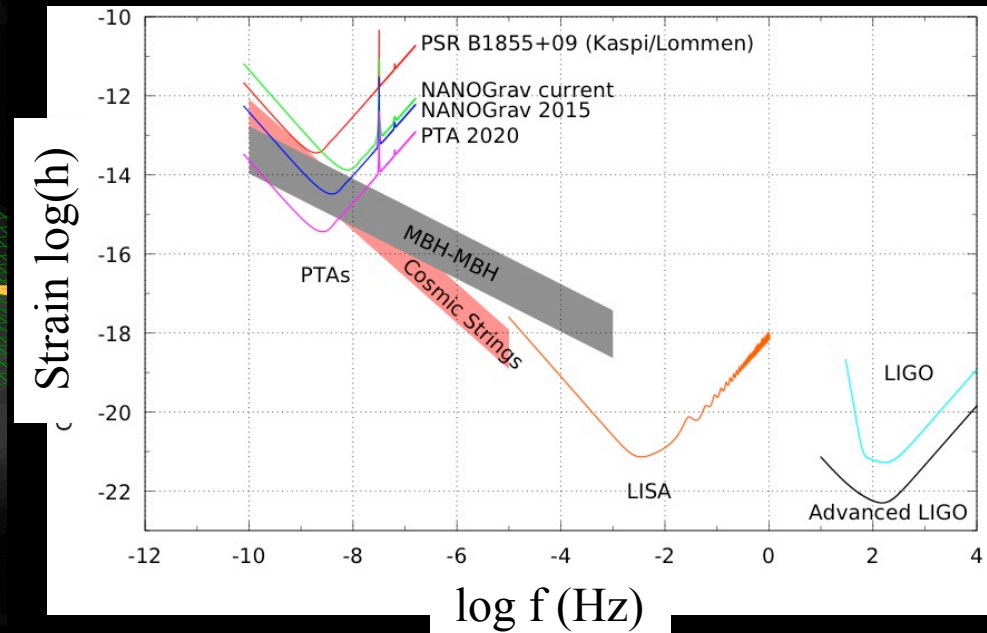
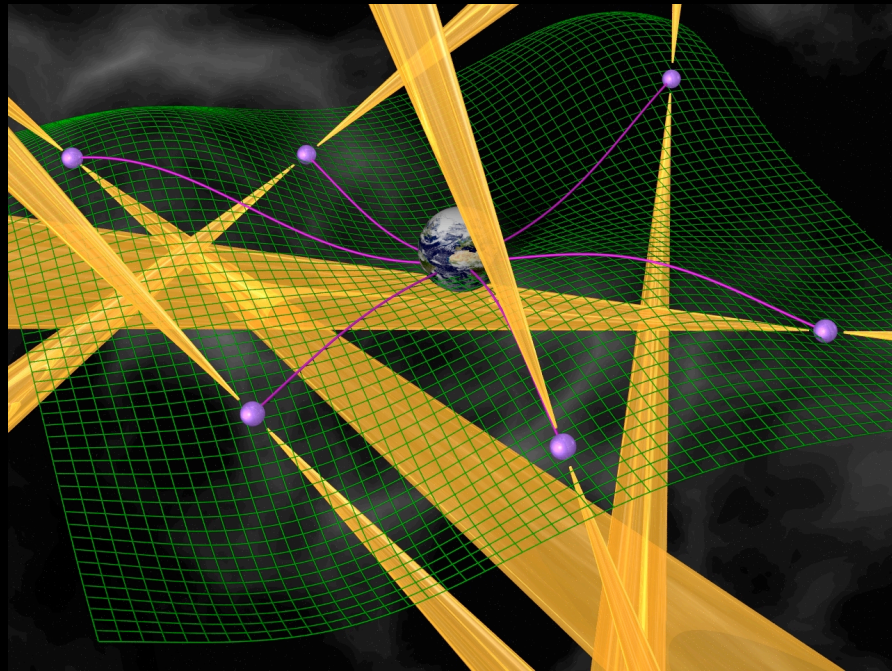


LST: BAOs,
supernovae, weak
lensing, ...



JDEM: supernovae,
...

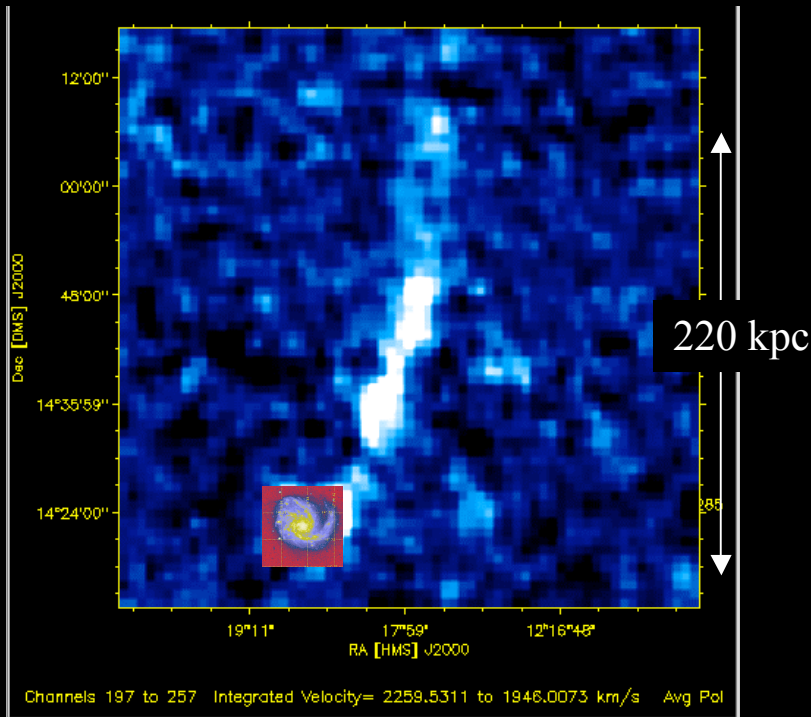
SKA: Gravitational Wave Detector



Test masses on lever arm

- **Pulsar Timing Array** = freely-falling millisecond pulsars
- LIGO = suspended mirrors
- LISA = freely-falling masses in spacecraft

Evolution and Environment

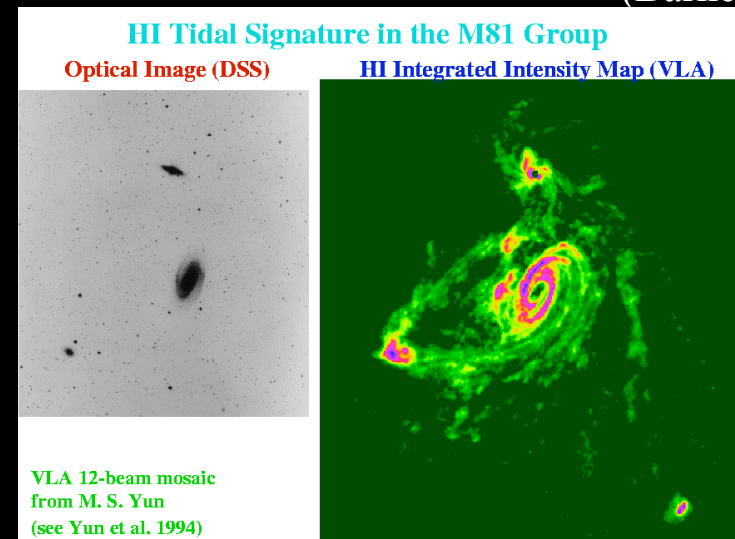


NGC 4254 in Virgo (ALFALFA)



(Barnes)

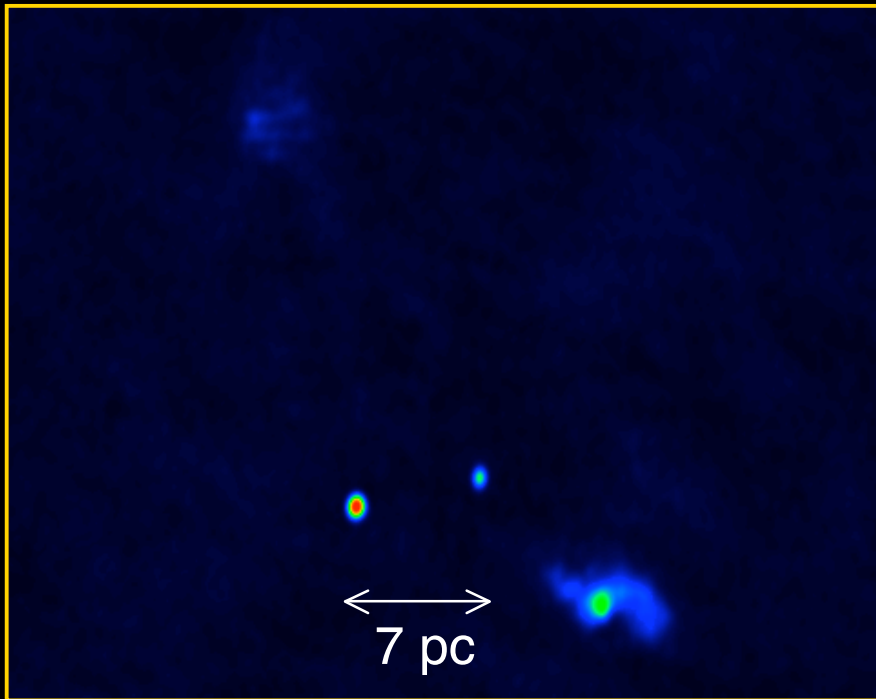
- Galaxy mergers recognized as an important part of galaxy assembly and evolution.



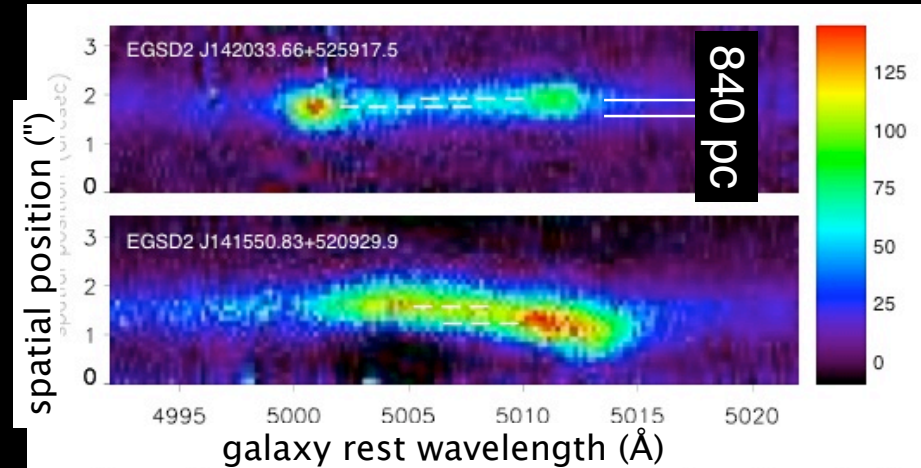
Binary Supermassive Black Holes



B0402+679 — VLBA



Rodriguez et al.



Comerford et al.

Emerging multi-wavelength evidence for large number of dual AGN nuclei

- VLBA (radio) imaging
- Keck II/DEIMOS spectroscopy
 - > 30%–50% of (early-type) galaxies show evidence for recent mergers

Fundamental
Physics

Dark Energy
Gravity
Strong Force

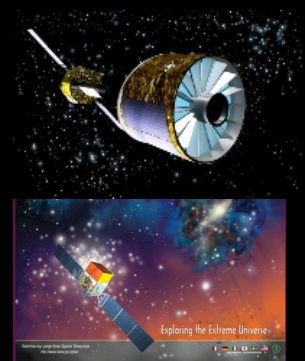


Fundamental Forces

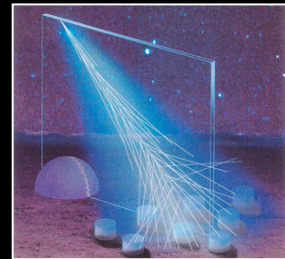
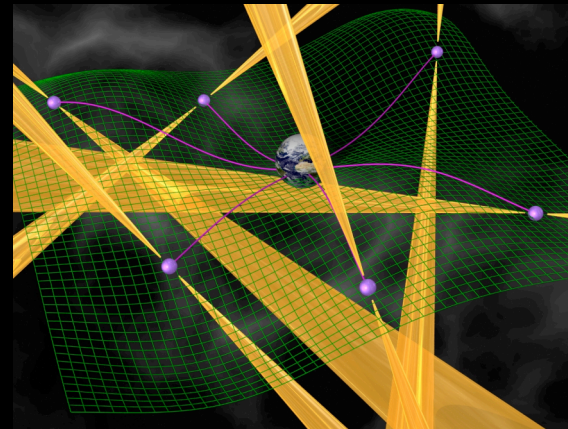


SKA: gravity, strong force, magnetism

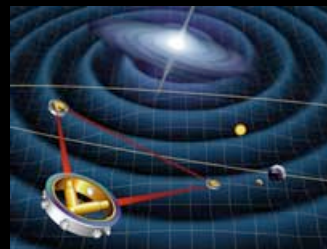
$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu} / c^4$$



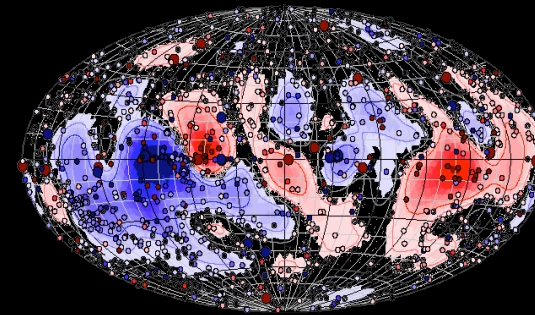
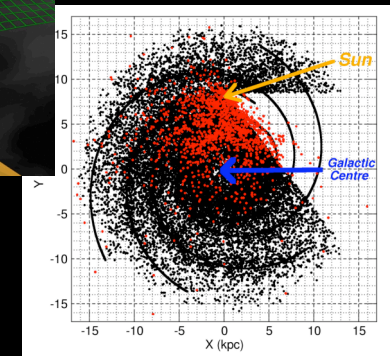
X- and γ -rays:
gravity, strong force



Auger: cosmic-ray propagation



LIGO, LISA:
gravity



21st Century Astrophysics



Fundamental Forces and Particles

- Gravity
- Magnetism
- Strong force

Origins

- Galaxies and the Universe
- Stars, Planets, and Life

“The Universe is patiently waiting for our wits to grow sharper.”

Photon
frequency/wavelength/energy

Time

Polarization

Sensitivity

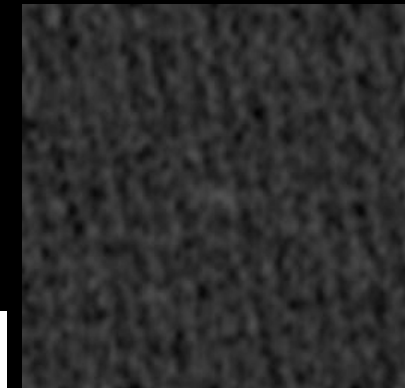
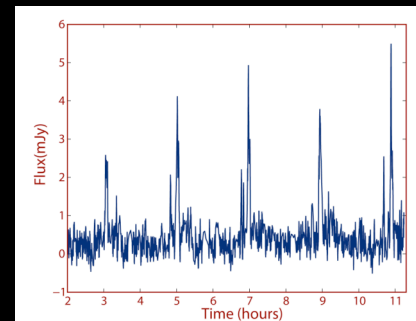
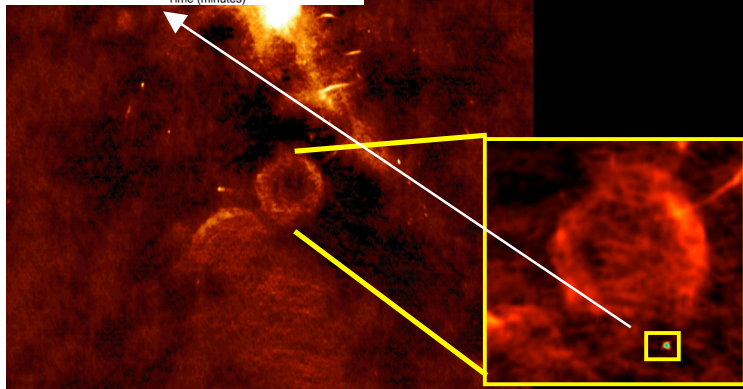
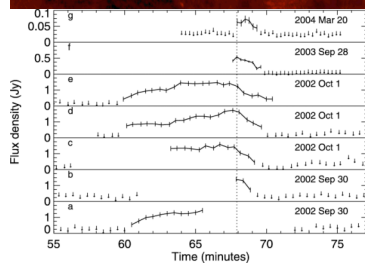
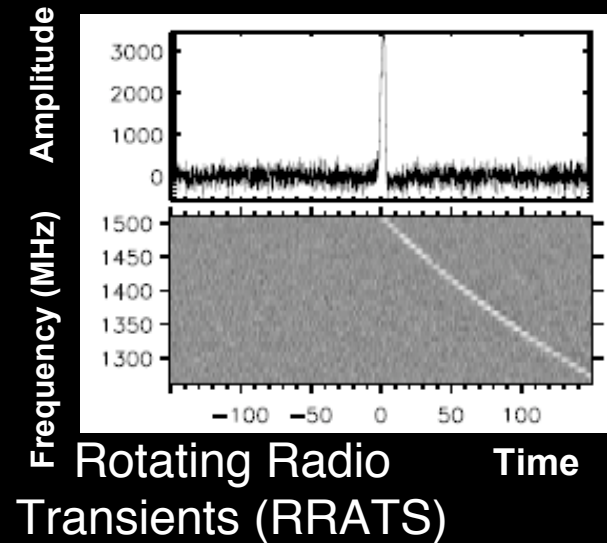
Field of View

Angular Resolution

The Dynamic Radio Sky



- Neutron stars
 - Magnetars
 - Giant pulses
 - Short GRBs?
- GRBs (γ -ray loud; γ -ray quiet?)
 - Afterglows
 - Prompt emission?
- Sub-stellar objects
 - Brown dwarfs
 - Extrasolar planets?
- Microquasars
- Scintillation
- UHECRs
- ETI
- Exploding black holes
- ???



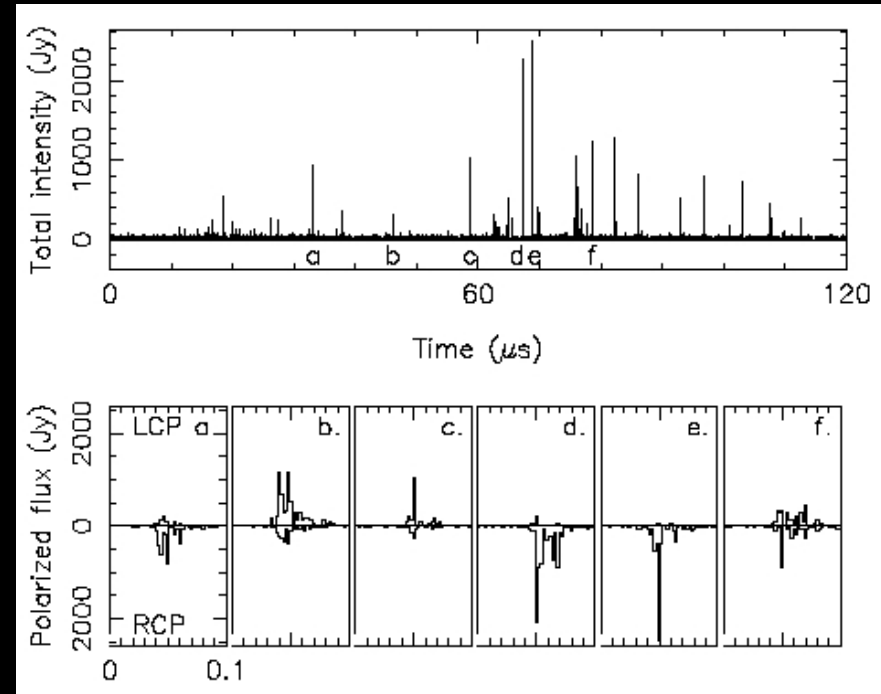
Pulsating Brown Dwarfs

Dynamic Radio Sky



All-sky surveys
(3C, NVSS, ...)

+
(?)

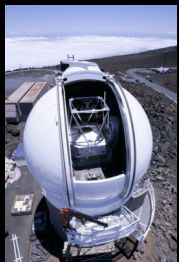


Nano-second pulses from the
Crab pulsar, from Arecibo

Dynamic Radio Sky and 21st Century Astrophysics



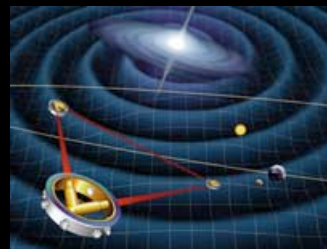
SKA



Optical
survey
telescopes



X- and γ -
rays



LIGO,
LISA

Transient sources are necessarily compact

➤ Locations of explosive or dynamic events

➤ Probe fundamental physics and astrophysics

• Radio signals modified by, and are powerful probes of, intervening media

- Dispersion
- Scattering
- Faraday rotation

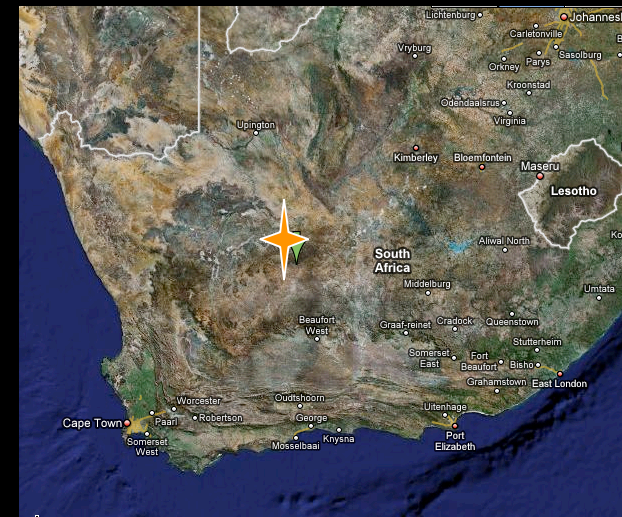
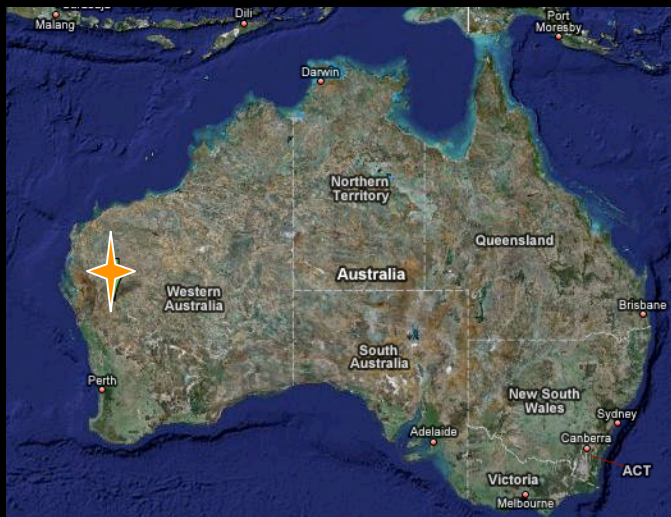
• Media include

- Interplanetary medium (IPM)
- Interstellar medium (ISM)
- Intergalactic medium (IGM)



An International Telescope

- Reference design
- “Preliminary Specifications for the SKA” (Schillizi et al. 2007)
- Technology development
 - U.S. TDP (\$12M)
 - EC PrepSKA (EUR 5.5M + matching)
- System Requirements Review
2008 January 29–30
- International Engineering Advisory Committee
2009 April 29 – 30
- Siting
- SKA Forum



SKA Technology



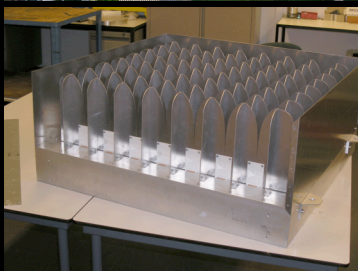
Novel antenna construction



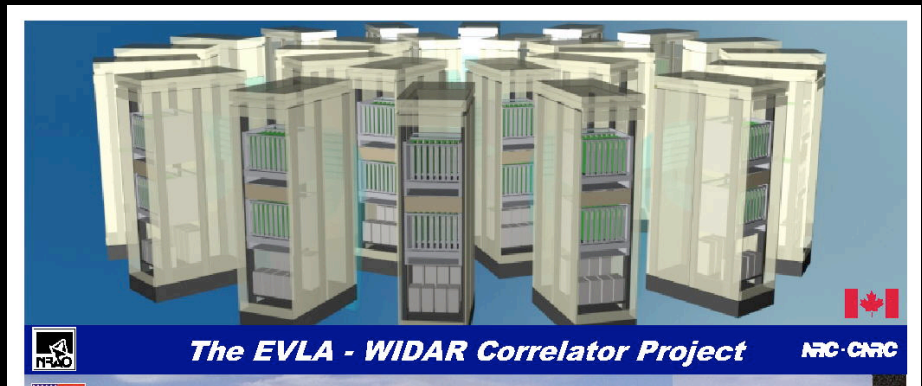
Fiber optic transmission



Ultra wide-band feeds



Phased arrays
(FoV expansion)



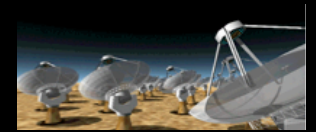
The EVLA - WIDAR Correlator Project



SKA Pathfinder



- Science pathfinding
- Novel antenna construction
- Sparse arrays
- Field of view expansion
- Wide-band feeds
- Signal transmission
- Processing and data management



Schedule for the SKA Program

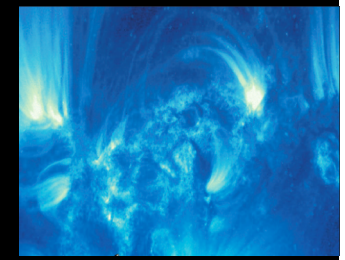
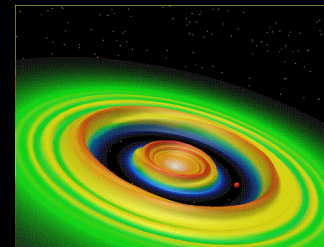
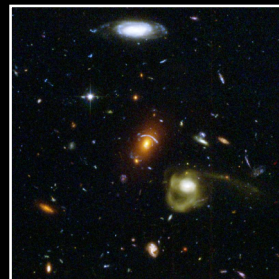
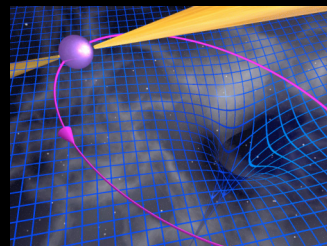
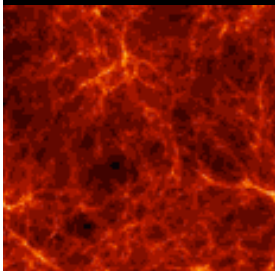


2008–2013	telescope design and cost
2012	site selection, Phase I construction funding approved
2012–2013	establish SKA organisation
2013–2018	Phase I implementation at low- and mid frequencies (< 10 GHz; EoR, H I, pulsars)
2017 →	early science with Phase I
2013–2018	high frequency technology development
2018–2022	Phase II construction at low- and mid frequencies
2023 →	Phase 3 construction at high frequencies

Square Kilometer Array

The Global Radio Wavelength Observatory

- Originally: “Hydrogen telescope”
 - Detect H I emission from Milky Way-like galaxy at $z \sim 1$
- SKA science much broader
 - ⇒ Multi-wavelength, multi-messenger
- On-going technical development
- International involvement



Origins

First Light

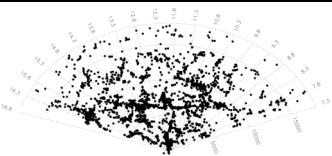
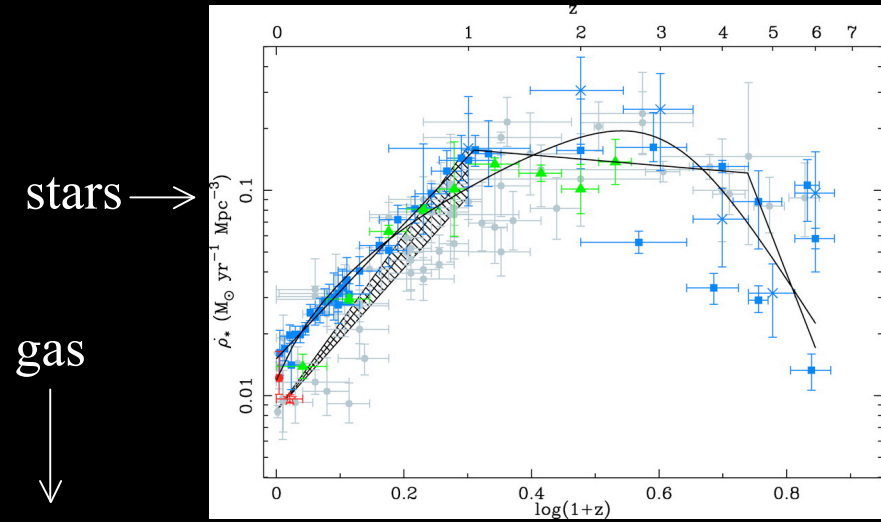
Galaxy Evolution

Astrobiology

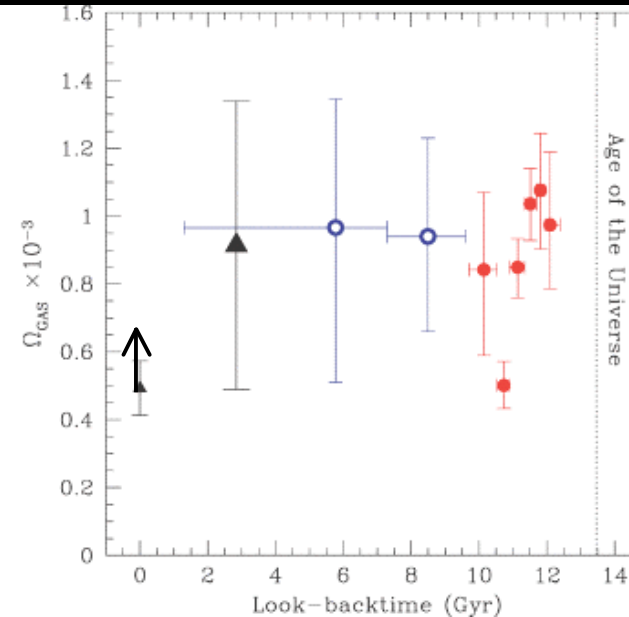
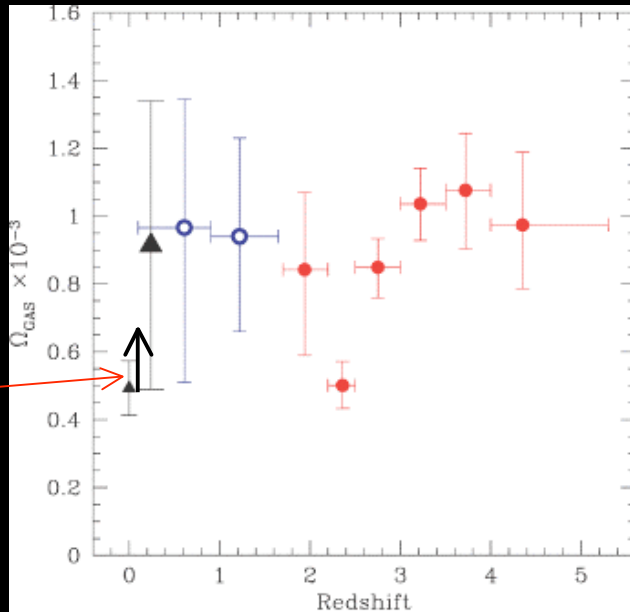
Galaxy Assembly Stars *and* Gas



- Stellar “downsizing” since $z \sim 1$
- ... but gas content unchanging!
- Gas content and dynamics becoming critical part of simulations.



HIPASS
(Parkes),
ALFALFA
(Arecibo)



Hopkins &
Beacom

Origins

First Light

Galaxy Evolution

Astrobiology

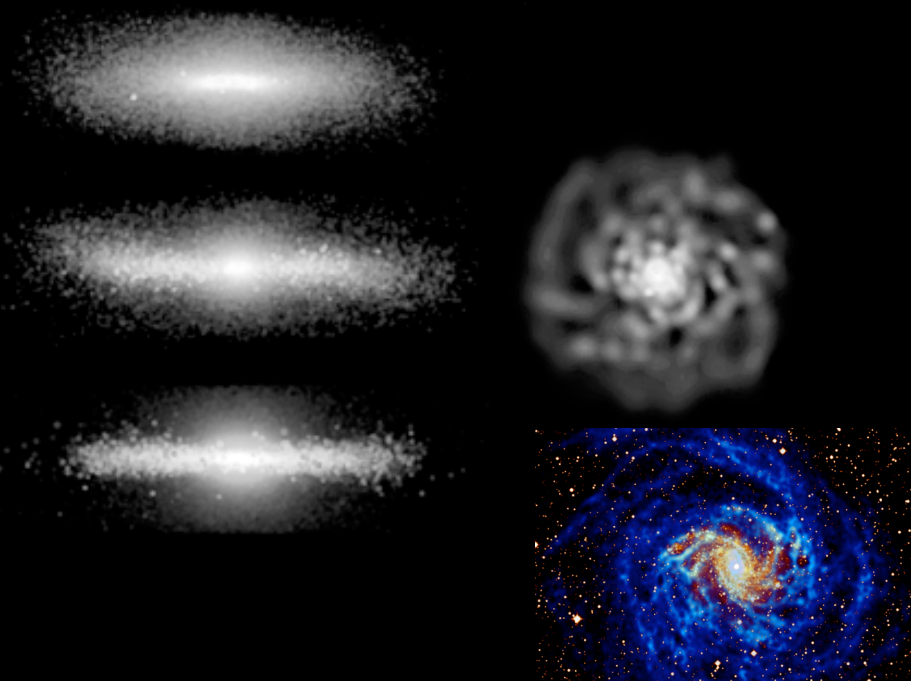
Galaxy Assembly

Stars *and* Gas

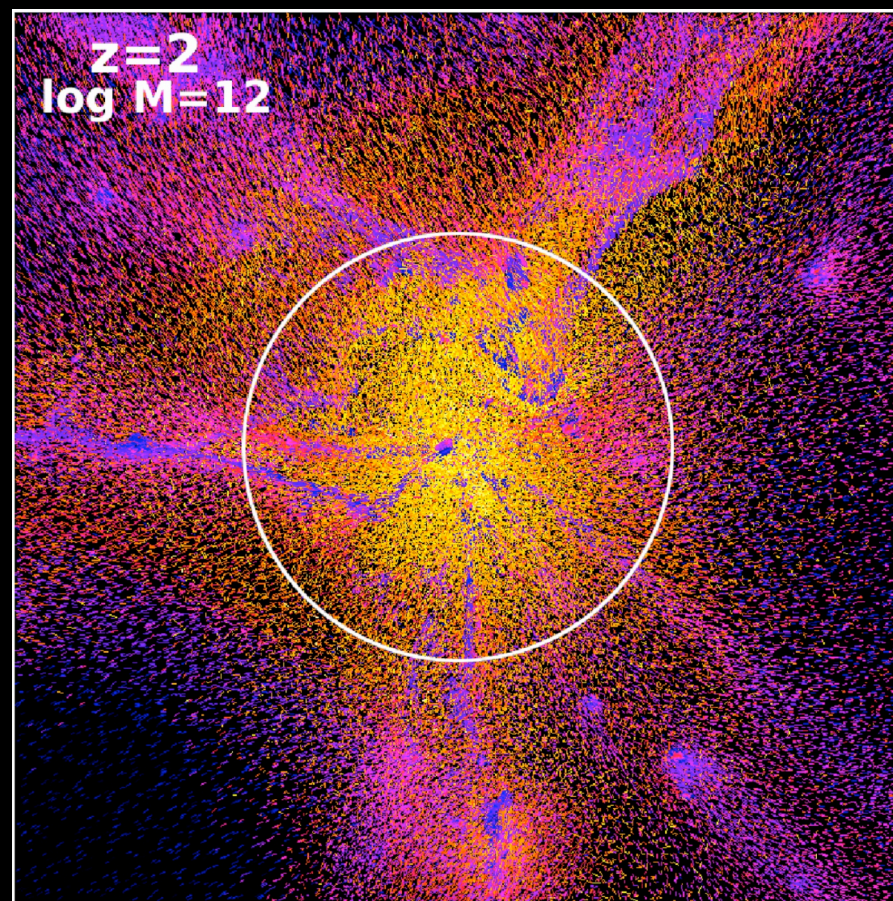


Gas content and dynamics
becoming critical part of
simulations.

Astronomy is an *observational*
science.



NGC 6946 (T. Oosterloo)



Keres et al.

... and Feedback

